The Impact Of Climate Change On The Energy-Efficient Refurbishment Of Social Housing Stock In Italy

THE IMPACT OF CLIMATE CHANGE ON THE ENERGY-EFFICIENT REFURBISHMENT OF SOCIAL HOUSING STOCK IN ITALY

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ABSTRACT

From the ‘40s to the late ‘70s, Italy implemented an extensive plan of public social housing. The building typologies and their urban aggregation plans have represented an high quality standard till today and well represented the national building stock; conversely, their energy performance is extremely poor, and their energy-efficient refurbishment have a key role in the national targets of GHG emissions reduction.

For these reasons, by historical research and survey of 145 social housing buildings, a building typology matrix with six references building has been identified, in analogy with IEE TABULA project. Then, some typical refurbishment measures have been analysed in term of global costs and energy response to climate change. The results of this study show that the measures with moderate performance level can be considered the most favorable in term of global costs reduction for the most of the economic and climatic scenarios considered.

INTRODUCTION

The European Directive 2010/31/EU, which aims to reduce energy consumption and environmental impact of buildings, was implemented with the identification of reference buildings, representative of the stocks of the member states, through research TABULA (IWU, 2012), followed by the EPISCOPE project (IWU, 2016), and the RePublic_ZEB project (Republic_ZEB, 2016), which is focused on the energy demand and CO_2 emissions of existing public buildings and their refurbishment towards nZEB.

In Italy, research TABULA was carried out by the research group TEBE (Corrado et al., 2014) which based its typological and technological research on the data base of the Piedmont Region, on the national housing census data (ISTAT, 2011) and on the analyses conducted by ENEA (ENEA, 2012).

The research ended with the definition of a reference buildings type matrix, where several kind of redevelopment have been applied in order to identify energetically optimal solutions under the cost-benefit profile. Finally, the results were used to emanate the Italian decrees concerning the minimum energy performance requirements for different types of intervention and the new buildings energy rating system.

The most critical aspects of the European methodology are:

- the representativeness of the reference buildings compared to national buildings stock;

- the energy performance calculation do not take into account climate change;

- the economic assessment , having to simplify the evolution of the extremely uncertain financial parameters, could fail to make completely reliable optimal costs identification.

This research starting from shared input data (construction types by historical periods, common types of refurbishment and related costs) has addressed the three above-mentioned aspects, taking into account a new set of reference buildings and a possible climate change projection for a region of central Italy, which is considered representative for global warming analysis (European Climate Adaptation Platform, 2016).

HISTORICAL ANALYSIS

In Italy, from 1949 to 1973 were activated two major plans of social housing construction (INA-CASA 1949-1963 and GESCAL 1963-1973), continued till the ‘80s (L. 457/1978), which have been considered very important for the following reasons:

- the set-up of building types that have turned into archetypes for the most of the residential buildings which were built in Italy in the postwar period;

- the urban level aggregation of these types, used as model for the expansion of many Italian cities.

The INA-CASA plan aim was to increase laborers’ employment promoting the construction of houses for low-income workers. In order to meet these goals, general directives were summarized in specific guidelines, collected in two booklets (INA CASA, 1949) (INA CASA, 1950) including the following recommendations:

- the use of a simple construction technology which makes extensive use of locally available material and does not require skilled labor;

- the use of building types, which must be simple and functional both in terms of space planning and hygienic facilities and that can be easily aggregated and multiplied at urban scale (typically suburban district) in order to guarantee a speed realization of the plan itself.

Within INA-CASA plan were constructed 2 million rooms representing approximately 13% of total rooms built in Italy in the same period.

INA-CASA plan have been object of several historical studies which show its relevance and its influence on residential architecture up to present day (Acocella, 1980), (Costa, 1985), (Secchi, 2000) (Capomolla et al., 2003), (Beneforti et al., 2012). This fact validates the choice of selecting reference buildings type matrix starting from social housing of INA-CASA plan.

The most successful INA_CASA type of building was the multi-family house and apartment block (Marta et al., 1963) whose layout is still widely used by private developers (Fantozzi ed al., 1992.) (Capomolla et al., 2003). Terraced house and tower building type were not described in the INA-CASA booklets and have been more rarely used. Multi-family house type has been preferred by designers in order to reduce construction and urbanization costs and to take advantage of their ability to characterize the urban space with the composition of the various districts through a single sign clearly perceptible on the plan.

Figure 1 shows the type of buildings "detached house" whose union generates the type "multi-family house and apartment block" and their urban level aggregations.

This building type summarizes unequivocally its typical invariant characters:

- the position of the stairwell;

- the number of apartment per stairwell (from 2 to a maximum of 3);

- a clear separation of the living area from the sleeping area (served by the bath);

- the wide balconies and loggias for outdoor family life.

With regard to apartment sizes, the 1st Booklet specifies that the minimum useful area (without loggias and balconies) should range from 30 to 90 m^2. The surfaces of the windows have to be not less than 1/6 of the floor area of the room. These solutions reflected the address of post-war planning manuals (CNR, 1953).

GESCAL Plan, from 1963 to 1973, continued substantially to adopt types and aggregation schemes borrowed from INA-CASA plan with the same recommendations regarding the apartment exposure, the distances between buildings, the courtyards and common stairs size, etc.), with the only differentiation in apartment sizes that were grouped into four types, with floor area from 64 to 112 m^2.

The Law 513 of 1977, "Ten Year Plan Construction", then reduced the apartment floor area from GESCAL standards, bringing them back to the INA-CASA standards.

The results of the national competition for housing type announced in 1978 by the IACP of Lombardy Region (Bernstein et al., 1978), highlights the substantial uniformity of these building types until today (ISTAT, 2011). The multi-family house type building results to be the most cost-effective response to the market demand and the most appreciated by the users (Monti et al., 2009).

From these premises, we believe that the examined building types fully represent the archetypes for residential buildings from the '40s to nowadays.

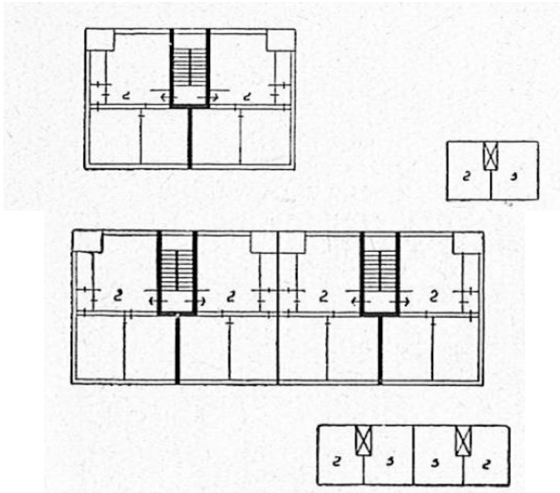


Figure 1 Detached multifamily house (above), base for apartment block (under) (INA CASA, 1950)

BUILDING TYPE MATRIX

A sample of 145 multi-family house and apartment block constructed in Pistoia (Beneforti et al., 2012), between 1946 and 1977 under the INA-CASA and GESCAL plans was selected for this study.

This sample has been divided into two historical periods characterized by different construction technologies:

- from 1946 to 1960 with 67 buildings;

- from 1961 to 1977 with 78 buildings.

This sample was analyzed following the methodology indicated in the TABULA and EPISCOPE projects. In particular it was analyzed the correlation of the thermal envelope areas with the main geometrical parameters, in order to derive a procedure for the estimation of the thermal envelope area on the basis of the main factors such as conditioned floor area, energy-dispersing envelope, number of floors, etc. The final scope is to use a simplified calculation of energy performance of buildings by these parameters (Cellai et al., 2003).

The general assumption is a linear dependency of:

- window area A_w and façade surface areas on the conditioned floor area A_f of the whole building;

- surface area of gross conditioned volume A_e and gross conditioned volume V_G.

In Italy, the A_e/V_G ratio is particularly important, because it's used for defining the limit of energy performance of buildings and their components; the volume and height of the buildings are also correlated with the number of storeys and apartments (nU) of the building.

Figure 2 shows the good correlation R^2 between window area and the conditioned floor area of the whole building, with values similar to those of TABULA project. Also the façade area on the conditioned floor area has a good correlation with $R^2 = 0{,}89$. The Figure 3 show the better correlation $R^2 = 0{,}93$ for A_e/V_G ratio.

Finally a good correlation, $R^2 = 0.89$, was found between the number of apartments (nU) and the volume V_G of the sample of buildings.

Therefore by means of a statistical analysis of the volume V_G of the buildings, three dimensional classes have been identified, limited by half of the standard deviation (SD/2) added and subtracted from the average value M of the volume of the buildings; the limit values are:

- inferior limit = M–SD/2 = 2700 m^3;
- superior limit = M+SD/2 = 4800 m^3.

For each classes of volume V_G it is possible to match the number of apartments (nU) which is reported in building type matrix of the Table 1. It also displays the number of buildings examined according to age and size class, with the largest number of buildings (30) in the class $V \leq 2700$ m^3 in the period 1961-1977.

This classification was compared with the TABULA matrix (Corrado, 2014), obtaining a substantial typological identity, with the only difference of a subdivision of the Multi-Family House type in two subtypes (small and medium dimensions), derived by statistical analysis and from the housing census 2011 (ISTAT, 2011).

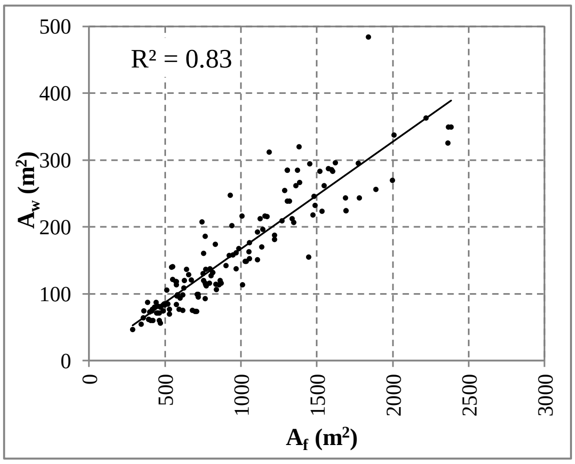


Figure 2 Regression analyses for A_w vs A_f

Tables 2 and 3 shows construction technologies and thermal transmittance of the building envelope elements, and the HVAC systems for each building-type of the matrix.

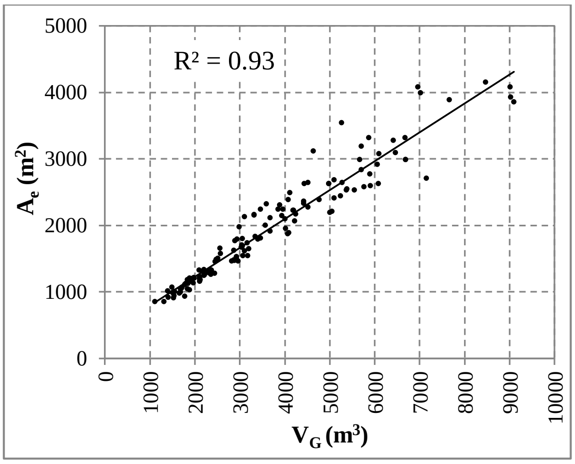
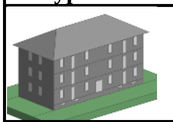
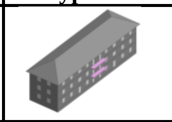
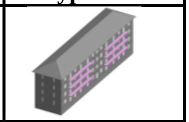
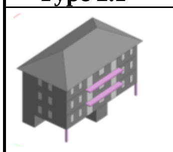
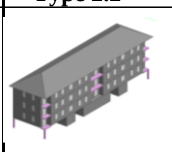
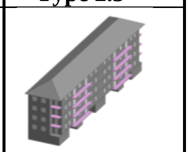


Figure 3 Regression analyses for A_e vs V_G

Table 1 Building Type Matrix

	DIMENSIONAL CLASS		
	(1) SMFH $V_G \leq 2700$ nU≤8	**(2) MMFH** $2700<V_G<4800$ 8<nU≤15	**(3) AB** $V_G \geq 4800$ nU>15
(1) 1946 1960	**Type 1.1**	**Type 1.2**	**Type 1.3**
			
	sample size: 26 buildings	sample size: 28 buildings	sample size: 13 buildings
	nU=6 A_f =496.2 m^2 V=1488.6 m^3 A_e=1181.1 m^3 V_G=1987.0 m^3 A_e/V_G=0.60 m^{-1} A_w=79.1 m^2 A_w/A_f=0.16	nU=12 A_f =872.4 m^2 V=2617.2 m^3 A_e=1845.2 m^3 V_G=3428.2 m^3 A_e/V_G=0.54 m^{-1} A_w=129.6 m^2 A_w/A_f=0.15	nU=24 A_f =1618.8 m^2 V=4856.4 m^3 A_e=2966.9 m^3 V_G=6293.7 m^3 A_e/V_G=0.47 m^{-1} A_w=266.0 m^2 A_w/A_f=0.16
(2) 1961 1977	**Type 2.1**	**Type 2.2**	**Type 2.3**
			
	sample size: 30 buildings	sample size: 26 buildings	sample size: 20 buildings
	nU=6 A_f =485.7 m^2 V=1457.1 m^3 A_e=1166.8 m^3 V_G=1893.1 m^3 A_e/V_G=0.61 m^{-1} A_w=89.7 m^2 A_w/A_f=0.18	nU=12 A_f =954.3 m^2 V=2862.9 m^3 A_e=2146.9 m^3 V_G=3697.5 m^3 A_e/V_G=0.58 m^{-1} A_w=176.4 m^2 A_w/A_f=0.18	nU=16 A_f =1633.2 m^2 V=4899.6 m^3 A_e=3130.1 m^3 V_G=6201.9 m^3 A_e/V_G=0.50 m^{-1} A_w=286.4 m^2 A_w/A_f=0.18

(1) Small Multi-Family House
(2) Medium Multi-Family House
(3) Apartment Block

Building and HVAC characteristics conform as much as possible to the data from TABULA project. Attic and basement of building type are unheated.

Table 2 Thermal properties of building-types envelope components

	BLDG. TYPES 1.1, 1.2, 1.3	**BLDG. TYPES 2.1, 2.2, 2.3**
External walls	Load bearing brick and stone masonry no thermal insulation U=1.50 W/(m^{2}K)	Hollow wall brick masonry no thermal insulation U=1.10 W/(m^{2}K)
Floors and ceilings	Reinforced brick concrete slab no insulation external floor: U=1.71 W/(m^{2}K) semi-exposed floor: U=1.39 W/(m^{2}K) semi-exposed ceiling: U=1.79 W/(m^{2}K)	
Roof	Pitched roof with brick-concrete slab; U=1.86 W/(m^{2}K)	
Basement	Concrete floor on soil; U=2.12 W/(m^{2}K)	
Window glass	Double 3-6(air)-3 clear glazing U_g= 3.23 W/(m^{2}K); g = 0.76; τ_v = 0.81	
Window frame	Aluminium without thermal brake U_f = 5.88 W/(m^{2}K)	

Table 3HVAC system of building-types

	BLDG. TYPES 1.1, 1.2, 1.3	**BLDG. TYPES 2.1, 2.2, 2.3**
Heating generation	Traditional gas boiler (individual system)	Traditional gas boiler (centralized system)
Heating control and emission	Hot water radiators (80°C/60°C) with zone thermostat	Hot water radiators (80°C/60°C) with thermostatic valves
Cooling	Direct expansion multi-split system (individual system)	
Ventilation	Natural ventilation provided by window opening. No mechanical system installed.	

CLIMATE CHANGE AND MEASURES

Climate boundary conditions

Since previous studies (De Wilde et al., 2012) highlight the importance of evaluating climate change impact in order to asses energy refurbishment strategies; the climate boundary conditions used in this research, incorporate possible results of global warming projections. In particular, energy simulations have been carried out with three different weather data sets. The first one was assumed as representative of the current climate up to year 2035. The other two represent the future climate change, as projected for the periods 2036-65 and 2066-95, within the Representative Concentration Pathways 8.5 scenario, which is used for the Intergovernmental Panel on Climate Change 5th Assessment Report considering a growing concentration of greenhouse gases beyond 2100 (Cubasch et al., 2013). This worst-case scenario was used in order to highlight critical responses of energy-refurbished building to future climate change conditions. The current weather data set is a Test Reference Year built according to UNI EN ISO 15927-4 (UNI, 2005) by CTI (Italian Thermotechnical Committee) on the basis of data collected between 2000 and 2009 in the city of Florence, that presents one of the hottest summer season and coldest winter season among the big cities of the central and southern part of Italy. The heating degree days and the cooling degree days of the current weather data used for this study, considering a base temperature of 20°C for winter and 23°C for summer, are respectively 2037 and 277 (UNI, 2008). The future weather data sets were processed by means of the "morphing" method (Belcher et al., 2005), adjusting the current weather data set on the basis of the results of high resolution regional climate model COSMO CLM developed by the Euro-Mediterranean Centre on Climate Change. Future soil temperature increase has been considered negligible in reason of its small extent and due to analysed building "on pilotis" typology.

Energy efficiency measures (EEMs)

The EEMs that have been analysed, were selected on the basis of the official data on the energy refurbishment measures that have been mostly applied within the tax benefit programs promoted by the Italian Government since 2006 (Nocera, M., 2015). These measures, furthermore, are in compliance to the TABULA project documents (Corrado et al., 2014).

In order to carry out a preliminary analysis, EEMs have been initially applied to Building Type 2.1, which represents the class of the building type matrix with the largest number of buildings. Every EEM is characterized by two level of performance: one moderate level (level 1) which just comply with the current minimum energy performance requirements for buildings and building elements (DM 06/26/2015) and a second level with advanced energy performance (level 2). In Tables 4 and 5 are reported the performance parameters, the investment and maintenance costs and the service life of the different EEMs.

In order to take into account the interaction between different measures, as, for example, the external envelope thermal insulation, which allows the reduction of the boiler size, the selected EEMs were combined in 18 EEM package.

Table 4 EEM on building elements

	LEVEL 1	**LEVEL 2**
name	**ETI-L1**	**ETI-L2**
External walls	U = 0.34 W/(m^{2}K) 0.07 m thick EPS[1] insulation layer on the external side C_I=C_R: 44.8 €/m^2	U = 0.23 W/(m^{2}K) 0.12 m thick EPS[1] insulation layer added on the external side C_I=C_R: 57.0€/m^2
Semi exposed ceiling	U = 0.30 W/(m^{2}K) 0.12 m thick Glass Wool[2] insulation layer on the upper side C_I=C_R: 12.2 €/m^2	U = 0.23 W/(m^{2}K) 0.16 m thick Glass Wool[2] insulation layer on the upper side C_I=C_R: 15.1 €/m^2

Floors	*Semi exposed floor* U=0.30 W/(m^{2}K) *External floor* U=0.32 W/(m^{2}K) 0.09 m thick EPS[1] insulation layer on the lower side C_I=C_R: 52.8 €/m^2	*Semi exposed floor* U = 0.23 W/(m^{2}K) *External floor* U = 0.23 W/(m^{2}K) 0.13 m thick EPS[1] insulation layer on the lower side C_I=C_R: 61.3 €/m^2
name	**W-DGLE**	**W-TGLE**
Windows	Double 4-16(air) -4 low e. clear glass U_g= 1.45 W/(m^{2}K) g = 0.60; τ_v = 0.77 Wooden frame U_f = 2.10 W/(m^{2}K) C_I=C_R: 530.5 €/m^2	Triple 4-12(air)-4-12(air)-4 low e. clear glass U_g= 0.78 W/(m^{2}K) g = 0.47; τ_v = 0.66 PVC frame U_f = 1.20 W/(m^{2}K) C_I=C_R: 622.1 €/m^2
Service life of external thermal insulation: 30 years Service life of windows: 50 years		

Table 5 EEM on heating system

	LEVEL 1	**LEVEL 2**
name	**H-CB**	**H-CBFC**
Generation system	Condensing gas boiler (central) C_I=C_R: 2454.7 € (ϕ_{Pn} = 20kW) C_I=C_R: 2808.7 € (ϕ_{Pn} = 45kW)	
Emission system	Hot water radiator (65°C/45°C) C_I=C_R: 214.3 €/kW	Fan coil (50°C/40°C) C_I=C_R: 1316.7 €/ap.
Control system	Weather compensator C_I=C_R: 847.0 €	
	thermostatic valves C_I=C_R: 250.0 €/ap	room thermostat C_I=C_R: 450.8/ap.
Service life of boilers and control system: 20 years; Service life of hot water radiators: 40 years; Service life of fan coil: 15 years; C_M for boilers, hot water radiators and control system is 1,5% of C_I per year; C_M for fan coils is 1,5% of C_I per year;		

Simulation and cost analysis assumptions

The 18 EEM packages have been simulated by means of dynamic energy simulation software Energy Plus v8.0, in order to calculate annual energy carriers demand and total primary energy demand for space heating and cooling in terms of kWh of energy for m^2 of useful floor area of conditioned space (kWh/m^{2}y). The following simplifications and assumptions have been adopted:

since the attic is unheated, the roof have not been thermally insulated;

- window additional thermal resistance due to night closing of shutters is not considered and no shading devices is considered;
- simplified calculation of thermal bridges by the increment of U-value of the building elements according to annex G.2 of UNI EN ISO 13790 (UNI, 2008-a);
- the soil temperature is calculated on the basis of current climate file and it is left unchanged for the future periods;
- heating and cooling system are available 24h/day and 7days/week in order to keep internal constant conditions of θ_o = 20°C winter and θ_o = 26°C in summer;
- constant (00-24 from Monday to Sunday) natural ventilation rate equal to 0.3 h^{-1};
- internal heat gains from occupants, lighting and appliances are considered constant and equal to 3.0 W/m^2 (TABULA Project Team, 2013);
- energy need for hot water preparation and lighting is not considered in the energy performance analysis;
- in order to calculate primary energy demand the most recent national conversion factors have been used (DM 06/26/2015).

Starting from the outputs of energy simulation a global cost analysis has been carried out in order to identify cost optimal energy refurbishment strategies. Global cost in term of net present value has been calculated for every EEM package, according to general principles and methodology of EU Regulation 244/2012 and its accompanying guidelines (European Commission, 2012).

The following assumptions have been adopted for global cost calculations:

- costs related to refurbishment works which have no influence on the energy performance or do not change between different EEM packages have been omitted;
- the calculation period is assumed to be 80 years;
- disposal costs have not been considered since, in long calculation periods, their influence is marginal due to discounting rate (E.U. Commission, 2012);
- two level of real discount rate have been analysed: 2% and 4% (E.U. Commission, 2012);
- As regards gas price projection after 2030, in addition to the value of 2.8% annual increase recommended by E.U. guidelines, a value of 0.1%, equal to that recommended for electricity, have been analysed (E.U. Commission, 2012).

EEM costs data have been gathered from existing cost databases which have been derived from local and updated market-based data (Camera di Commercio di Firenze, 2015) (Ministero dello Sviluppo Economico, 2013). Service life duration and maintenance costs of building elements and HVAC components have been gathered from (UNI, 2008-a) and (Di Giulio, 1999). Electricity prices includes taxes and equal to 0.188 €/kWh for common uses (e.g. auxiliary equipment of central heating system) and 0.292 €/kWh for individual uses (e.g. individual multi-split system). Gas prices includes taxes and vary from 0.457 €/Sm^3 to 0.733 €/Sm^3 depending on yearly demand (AEEG, 2016).

DISCUSSION AND RESULT ANALYSIS

The primary energy demand and the global cost of the different EEM packages have been calculated under four different economic scenarios (E.U. Commission, 2012):

- Scenario 1: 4% discount rate coupled with a low gas price after 2030;
- Scenario 2: 4% discount rate coupled with a high gas price after 2030;
- Scenario 3: 2% discount rate coupled with a low gas price after 2030;
- Scenario 4: 2% discount rate coupled with an high gas price after 2030;

Then, these scenarios have been analysed both considering (YCC) and not considering (NCC) climate change effects on energy demand.

Figure 4 shows the results regarding scenario 1 which is the most favourable to high performance – high initial cost measures and scenario 4 which is the most favourable to moderate performance – low initial cost measures.

Figure 5 shows the effect of different discount rates representing the results for the eight first cost-optimal EEM packages considering each scenario.

Table 6 shows the cost optimal solution of different economic scenario with and without climate change.

From the analysis of the results, it can be seen that:

- the effect of climate change does not favour 2nd level external thermal insulation measures regardless of the economic and climatic scenario;
- considering the typical A_w/A_f of the examined building sample, climate change scenarios privilege the use of windows with advanced thermal insulation (triple glazing);
- in general the solution with a moderate level of external thermal insulation (ETI-L1) and double low e. glazing windows (W-DGLE) appears to be, regardless of the different scenarios, the most reliable solution since it appears 6 times out of 8 in Table 6;
- the discount rate value relevantly affects the global cost of different EEM packages with variations around 350 €/m^2 between scenarios 1, 2 and 3, 4;
- total primary energy demand of different EEM packages increases by about 5 kWh/m^{2}y under climate change conditions.

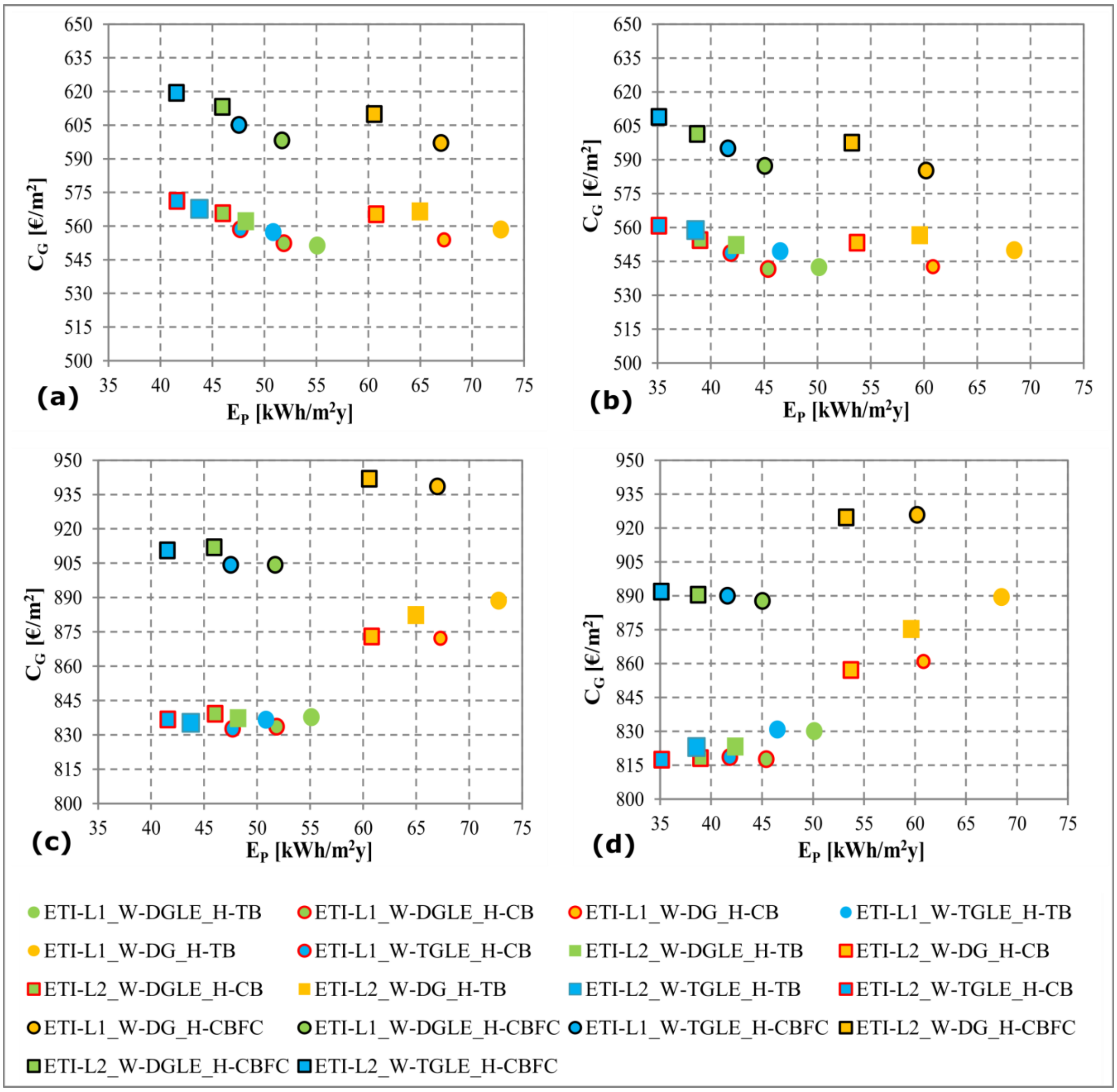


Figure 4 C_G / E_P plots for scenario 1-YCC (a), 1-NCC(b), 4-YCC (c) and 4-NCC (d)

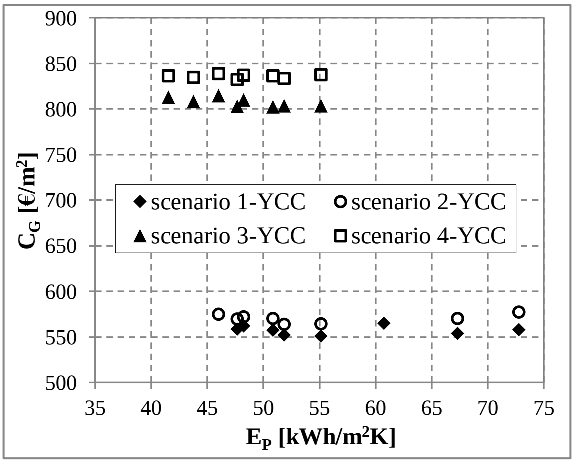


Figure 5 Comparison between the first eight cost-optimal solutions of scenario 1, 2, 3 and 4(all YCC)

Table 6
Optimal-cost solution in different scenarios

TECHNICAL SOLUTION	C_G (80) [€/m^2]	E_P [kWh/m^{2}y]
Gas price increase after 2030 = 0.1%; r = 4%; YCC		
ETI-L1_W-DGLE_H-TB	551	55
Gas price increase after 2030 = 2.8%; r = 4%; YCC		
ETI-L1_W-DGLE_H-CB	564	52
Gas price increase after 2030 = 0.1%; r = 2%; YCC		
ETI-L1_W-TGLE_H-CB	803	48
Gas price increase after 2030 = 2.8%; r = 2%; YCC		
ETI-L1_W-TGLE_H-CB	833	48
Gas price increase after 2030 = 0.1%; r = 4%; NCC		
ETI-L1_W-DGLE_H-CB	541	45
Gas price increase after 2030 = 2.8%; r = 4%; NCC		
ETI-L1_W-DGLE_H-CB	558	45
Gas price increase after 2030 = 0.1%; r = 2%; NCC		
ETI-L1_W-DGLE_H-CB	774	45
Gas price increase after 2030 = 2.8%; r = 2%; NCC		
ETI-L2_W-TGLE_H-CB	817	35

In order to evaluate the effect of exposure, Building 2.1 has been simulated turning its short axis from the optimal orientation of North-South to the orientation West-Est, which is the most critical one for cooling loads. In consequence, primary energy demand rises within the range 23% - 33% because of both heating and cooling demand increase. Global costs rise of an average value of 7% for scenarios 1 and 2; while the average increase for scenarios 3 and 4 is 9%, both with and without climate change conditions. The cost-optimal solution for rotated Building 2.1 is ETI-L1_W-TGLE_H-CB, which is characterized by a moderate level of external thermal insulation, triple glazing windows and condensing boiler. This solution presents the lowest global cost in all the 4 scenarios which include climate change projections and in 6 out of 8 scenarios in total. In summary, cost-optimal configurations for West-Est short axis orientation require windows with better thermal performances compared to North-South short axis orientations.

CONCLUSION

This research investigated global costs and primary energy demand of common energy refurbished measures applied to building models, which are representative of the Italian social housing stock build from 1946 to 1977. Different climatic and economic development scenarios have been considered. Although the results cannot be used to provide general and conclusive solutions, they are useful for highlighting a trend of the effectiveness of climate change adaptation measures in central Italy, where Florence, which presents an interesting climate for this research, is placed.

The cost analysis shows that some economic assumptions such as discount rate value can affect the selection of cost-optimal refurbishment strategies more than energy carrier's price future trend.

In summary, preliminary results of this research indicates that for the most of the economic and climatic future scenario analysed, moderate levels of thermal insulation and heating system efficiency that are already required by Italian regulations could be a cost-optimal limit beyond which it is not convenient to move. For this reason, the research continues with further investigations and simulations of several scenarios.

NOMENCLATURE

nU, number of units in the building;
A_f, useful floor area of conditioned space;
V, net conditioned volume;
A_e, surface area of gross conditioned volume;
V_G, gross conditioned volume;
A_w, window area;
U, thermal transmittance;
U_w, window thermal transmittance;
U_g, glass thermal transmittance;
U_f, frame thermal transmittance;
g, solar factor;
τ_v, light transmittance;
E_P, primary energy;
C_G, global cost in term of net present value;
r, real discount rate;
ϕ_{Pn}, generator output at full load;
n, natural ventilation air change rate;
C_I, initial investment costs;
C_R, replacement costs for component or systems;
C_M, maintenance costs;
θ_o, operative temperature;

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